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Characterization of Water Quality in Bungboraped Wetland, Thailand Using Self Organizing Map for Water Quality Management

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Abstract

Bungboraped is the largest wetland in Thailand. The water quantity and quality, based on people's activities around the wetland, is currently speeding up environmental degradation. The government has organized projects that aim to improve the water quality. These projects are currently having a negative affect on the quality of the water. The aim of this research was to analyze characteristics of water quality. Water parameters with 13 variables data were collected from 2004 to 2016, from 5 surface water stations located in the wetland area. Data analysis was subsequently performed using Self Organizing Maps (SOM) and Principal Component Analysis (PCA). Six distinct clusters were obtained based on the similarity of their water quality parameters. There were five clusters, where the water quality was not very good. This was related to the location and pattern of dredging and pumping of the sediment, water quantity and runoff. However, the last cluster was shown to be in good condition, because there was enough water present to self-purify, and was clearly separated for PCA. The result from this study will be the basic information leading to the activities that increase the water quality in the Bungboraped wetland.

Keywords: Bungboraped wetland; Self organizing map; Water quality

1. Introduction

Bungboraped, a marsh wetland is located at the outlet of Bungborapet basin. In 1930, King Rama VII constructed a dike for the purpose of breeding aquatic animals. This has reduced the flow of water, resulting in the largest freshwater area in Thailand. Most of the freshwater in Bungboraped is in the limnetic zone where light can reach the water surface. This means a variety of aquatic plants are able to grow well at different depths. The species of living organisms can also live at different depths, such as plankton, fauna, fish, reptiles etc. From the above reasons, the wetlands have huge biodiversity, causing people to take advantage of existing resources, utilizing water resources and irrigation.

Due to human activities, in the combination of point sources (local communities, fish culture pond, tourist zone restaurants and hotels) non-point sources (runoff and agricultural area) and government projects (dredging and pumping sediment and aquatic management), has led to poor water quality in the watershed and in the wetland (Sriwongsitanon *et al*., 2007). Soil erosion in the Bungborapet basin was 2.89 tons per year (Anuttarunggoon *et al*., 2018), causing the government to focus on the operation of the dredging project.

It is necessary to use self-organizing maps (SOM) as a research tool as it can explain characterization of water quality conditions (Sharif *et al*., 2015) in this area. The water quality data was used to classify the monitoring station and time into different clusters, with the use of SOM. The SOM which is an unsupervised artificial neural network, is a powerful method for analysis and can classify complex data with non-liner relationships and identify model sensitivity (Kim *et al*., 2018). Recent applications of SOM have been widely useful for ecological application, water resource, agriculture and land use planning which include specific studies such as heavy metal removal performance, nutrient removal performance, variation of dissolved fulvic acid and mechanistic eutrophication (Park *et al*., 2004; Avakul and Jutagate, 2012; Tasdemir *et al*., 2012; Gu *et al*., 2019; Lee and Scholz, 2006; Zhang *et al*., 2008; Yu *et al*., 2014; Kim *et al*., 2018).

Since there is no specific and accurate way to manage the water in Bungboraped wetland, there is a research gap in water quality management. In this regard, the aim of this research was to study characteristics of water quality in space and time. Results from this research will be the basic information on water quality management in the wetlands.

2. Materials and method

2.1 Study area

Bungboraped Wetland is the largest shallow lake in Thailand (Chaichana and Choowaew, 2014), located in Nakhonsawan Province, in the central part of the country. It has an area of 212 square kilometers that covers both land and water areas. The terrain is flat and quite smooth, causing the water to sit in the wetland because the depth is not much different from the rest of the area, with an average depth of 1.19 meters (Anuttarunggoon *et al*., 2017), resulting in a variety of species of fish, birds and aquatic plants (Choowaew *et al*., 2014). In addition, there are 4,286 households of agriculture, fisheries and communities (Bungborapet Research and Training Center, 2015). Administration consists of the Department of Fisheries that takes full responsibility for the area and the Department of National Parks, Wildlife and Plant Conservation is tasked with the conservation area in the middle of the wetland.

2.2 Data Analysis

The samples were arranged in a matrix with rows representing samples (station x year, i.e., BP01 May 2004 is the sample from station BP01 in May 2016) and columns of water quality parameters with 13 variables, consists of water temperature (WT-°C), pH, turbidity (Tur-NTU), suspended solids (SS-mg/L), conductivity (Cond-µs/cm), dissolved oxygen (DO-mg/L), biochemical oxygen demand (BOD-mg/L), total phosphorus (TP-mg/L), nitrate-nitrogen (NO_3^--N-mg/L), nitrite-nitrogen (NO_2^--N-mg/L), ammonia (NH_3-mg/L), total coliform bacteria (TCB-MPN/100ml) and fecal coliform bacteria (FCB-MPN/100ml). Water quality data was kindly provided by the Pollution Control Department (PCD) of Thailand (Pollution Control Department, 2018). It spans 14 years (2003-2016) from five surface water stations around Bungboraped wetland (Figure 1). Seventy samples were selected using all of the data and all of parameters.

The SOM consist of input and output layers which are connected by weight vectors. In this study, the input layer contained 13 neurons connected to 70 samples and the output layer is displayed to a hexagonol lattice. The algorithm automatically analyses to classify sample vectors on the map by 13 set similarities descriptors (water quality). During the mapping process, the neurons in the output layer were matched against each other by selecting the best matching unit (BMU), represented by minimum distance between the weight vector and sample vectors. Detailed descriptions of computation and protocol of SOM algorithms are widely utilized. The correct amount of neurons was based on a formula $c = 5 \times \sqrt{n}$ proposed by the laboratory of Computer and Information Science (CIS), Helsinki University (Kohonen, 1982), where the C is neuron

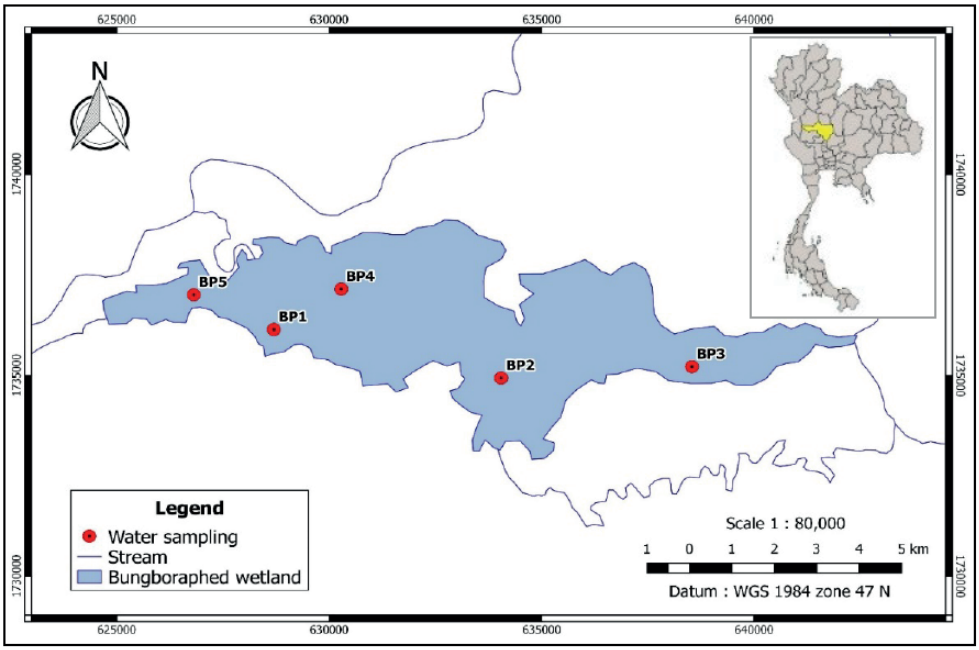

Figure 1. Location and water stations in Bungboraped wetland, Nakhonsawan province.

number (cell) and the n is number of sample. Therefore, the output layer comprised of 42 neurons organized in an array with 7 rows and 6 columns. Meanwhile, cluster boundaries on SOM map were performed by hierarchical cluster analysis (ward distance) using Euclidian distance between weight vectors of each unit, the best cluster is minimize sum of squared of distances (Ozaki *et al*., 2003; Tudesque *et al*., 2008). Then, SOM clusters were tested in order to study the covariance of the predictor, The analysis of similarity (ANOSIM) was performed for significant different among clusters using occurrence probability. Principal Component Analysis (PCA) was used to assess the structure of the variables being used as predictors (Fratarcangeli *et al*., 2019), and to examine the interrelationship between clusters and water quality parameters. This was also tested using the Monte-Carlo method with 1000 random permutations (Avakul and Jutagate, 2012). All statistical analyses were computed using MATLAB software and program R (R core team, 2018).

3. Results and Discussion

3.1 Characteristics of water quality

MATLAB software was created by a group of cells with parameters similar to each other. This diagram shows that the water quality is split into 42 cells. SOM can divide relationships into 6 clusters (Figure 2). The diagram can be divided into 6 legs (Figure 3). The SOM constructed each parameter to the map and the different colors were similar, if not the same (Figure 4). In Cells, the series data contained in each cluster consisted of space and time. ANOSIM test found significant differences (*p-value* < 0.05). The group of clusters that indicates the characteristics of activities that affect water quality in Bungboraped wetland were 6 clusters and the weight vectors neurons revealed the influence of each cluster in boxplot (Figure 5). These can indicate the quality of the water resource from class 3 of the national standard of surface water quality of Thailand (Enhancement and Conservation of National Environmental Quality, 1994). Moderately clean fresh surface water resources can be used for consumption and agriculture.

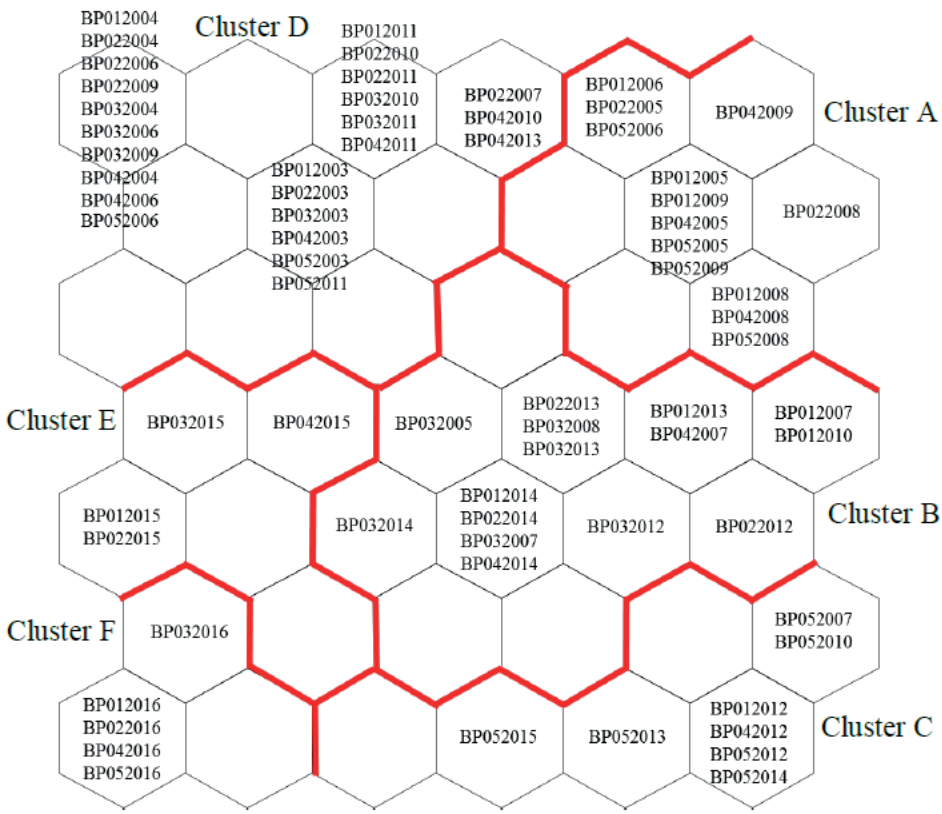

Figure 2. The output layer comprised of 42 neurons organized in an array with 7 rows and 6 columns which clustered in 6 clusters (A, B, C, D, E, F) by space and time on SOM.

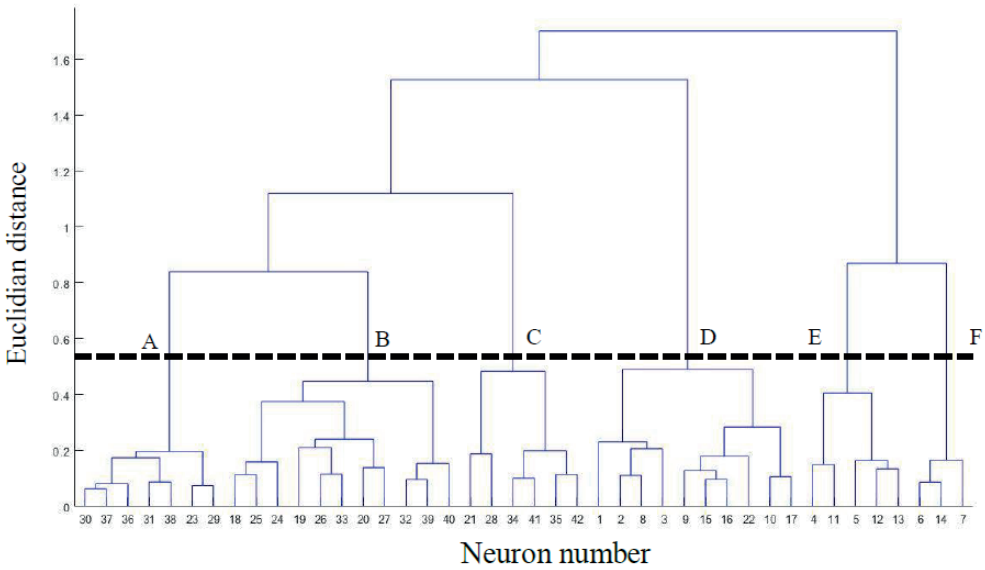

Figure 3. The Dendrogram show groups of similarity of cell on SOM.

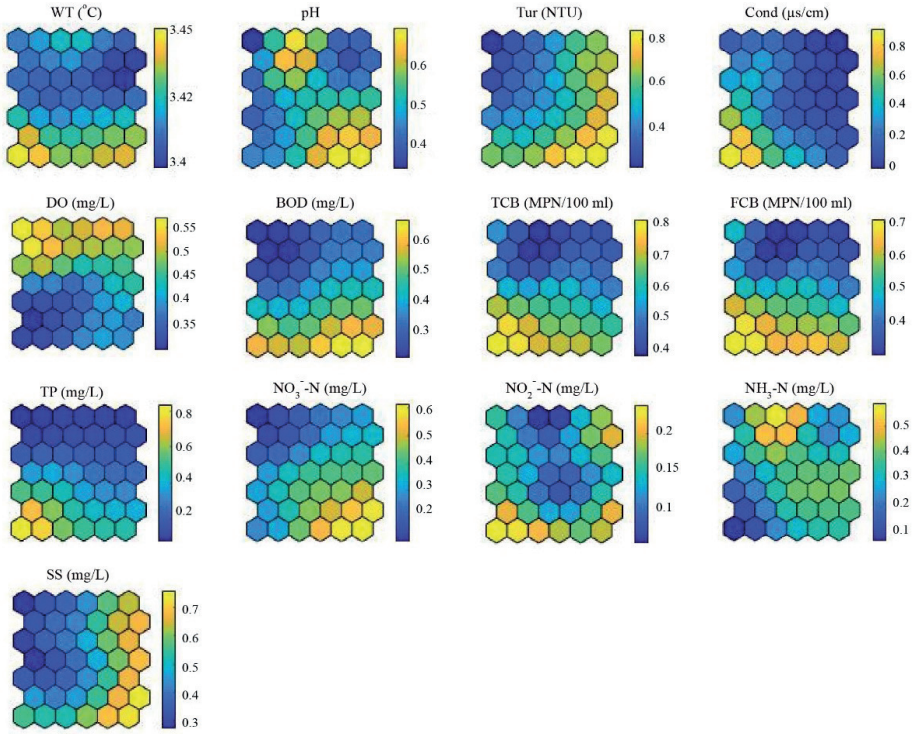

Figure 4. The contribution of 13 parameters are SOM map model. Yellow areas are high value input of each parameters.

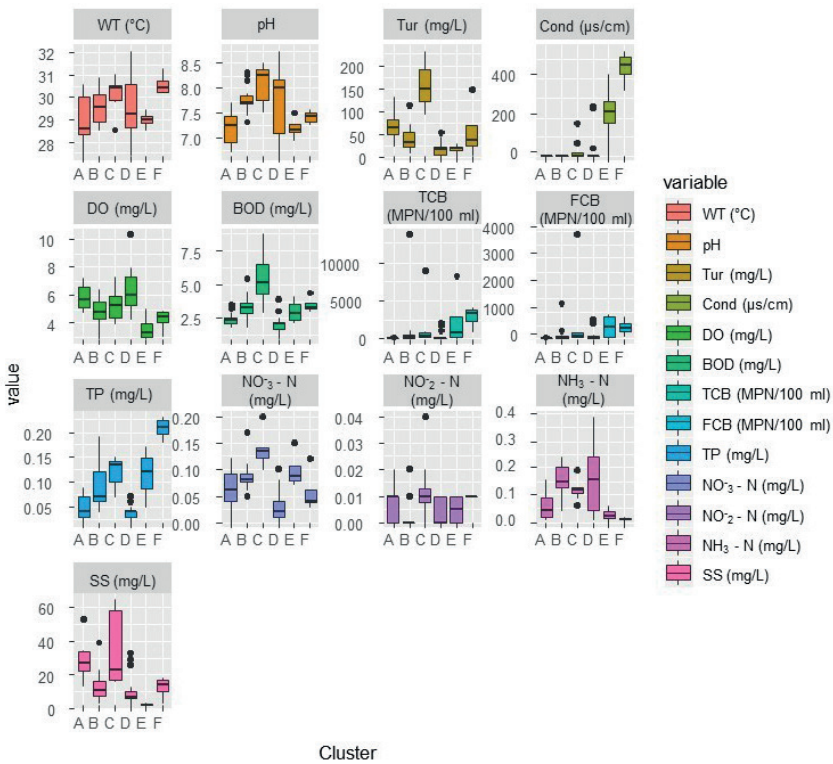

Figure 5. Boxplot show valued distribution of each parameters in 6 clusters. The large box shows high variation between each cluster. The number of replications in each cluster is 13 (cluster A), 15 (cluster B), 8 (cluster C), 25 (cluster D), 4 (cluster E) and 5 (cluster F).

The results of SOM clusters were as followed:

3.1.1 Cluster A

This water quality group was formed in the middle and lower part of wetland (BP1, BP2, BP4 and BP5). There was an increase in the amount of water, leading to water flowing over the dike during the wet period in the 2005-2009. The BOD was over Thai standard. It led to high concentrations of Tur and SS due to the boat pumping sediment process conducted by the Department of Fisheries, causing sediment to spread in the water until more of the oxygen was utilised by microbial organisms to decompose organic compounds in water (Aniyikaiye *et al*., 2019). The water quality was found to be poorer in the dry period than in the wet period (Netpae and Phalaraksh, 2010).

3.1.2 Cluster B

This water quality group was formed only in the middle and upper part of the wetland (BP1, BP2, BP3 and BP4). The water quantity did not exceed the dike during the wet period in the 2012-2014. The BOD was over Thai standard. It led to high concentrations of TCB and Tur in the water, as it was mostly extracted for irrigated rice growing in encroached areas around the wetland (Sriwongsitanon *et al*., 2007), along with cow raising and wastewater from rural communities in this area. However, the pumping sediment process carried out by the Department of Fisheries in the middle and upper areas has lower water quantity than cluster A, effect on Tur value.

3.1.3 Cluster C

This water quality group was formed, focusing on only the middle and lower parts of wetland (BP1, BP4 and BP5), which contained poor water quality because it faced with drought in 2012 and the largest dredging by machine. Subsequently, the BOD was over Thai standard, as it had high concentrations of WT, pH, Tur, SS, and FCB. The extent of drought-related effects and damage ranges from humans to environmental systems and the impacts on water quality (Kim *et al*., 2019).

3.1.4 Cluster D

This Cluster is the best of water quality group in the wetland. All water quality parameters were below Thai standard. The water quality was more prevalent during the wet period and flooding in 2006 and 2011. The flow of water makes the water resource to self-purification if even though it did not reach the clean water zone, the water was longer purification distance so that the self-purification process can run correctly (Zubaidah *et al*., 2019). The variation of river flow discharge in different seasons can modify the assimilation capacity up to 97% (Monfared *et al*., 2017) which is consistent with research in 2011, which found that the overall water quality of the wetland was in good condition (Chaichana and Choowaew, 2013).

3.1.5 Cluster E

This water quality group was formed only in the middle and upper part of wetland (BP1, BP2, BP3 and BP4) in 2015. The BOD and DO were over Thai standard and had high concentrations of TCB and FCB due to wastewater from rural communities. These results were consistent with the sewage in Amphawa community which contains traces of FCB over the standard amount (Kasemsawat *et al*., 2018) and high concentration runoff which was caused by the fermentation of humus in paddy fields and rotten grass in the canals that lead down to the wetland. This caused microorganisms to consume more oxygen to digest large amounts of organic matter, and with this, DO is greatly influenced by the BOD level in the water bodies (Aniyikaiye *et al*., 2019). With the consumption of oxygen by components like organic matter in sediment and water, the available DO in the hypolimnion was slowly reduced in time (Huang *et al*., 2014).

3.1.6 Cluster F

This group of water quality was caused by the drought that started at the beginning of 2016, resulting in drought and water bodies were separated aparts, causing the BOD to be over Thai standard

and had high concentrations of Con, TCB and FCB in all areas. In 2016, the average annual rainfall for Thailand was about 11% lower than the average per year and the average temperature was higher than normal (Meteorological Department, 2016), causing a drought in Thailand. It was related with (Sriwongsitanon *et al*., 2009) that has highlighted evaporation as the biggest contributor to water loss from the Bungboraphed wetland. Climate change was also expected to have some effect, with increasing temperatures and changing rainfall patterns (Avakul and Jutagate, 2012). Therefore, the wetlands suffered a bad drought, causing the high concentrations of parameters, due to the cattle raising and wastewater from rural communities.

3.2 Principal component analysis (PCA)

A study of the relationship groups, and the different factors in various groups from SOM analysis was conducted using Principal Component Analysis (PCA). The group in good condition in the cluster D, was clearly separated in quadrat 1. Groups had similar characteristics but were in different locations for clusters A and B, while cluster C was separated into quadrat 2 because the dredging and water use for activities affected the quantity of water in the wetland. For clusters E and F, water quality problems were likely to be in a similar condition to that as in quadrat 4 because that was affected by the concentration of wastewater from the upper watershed (Figure 6). For Monte Carlo testing found that there were significant differences (*p-value* < 0.001).

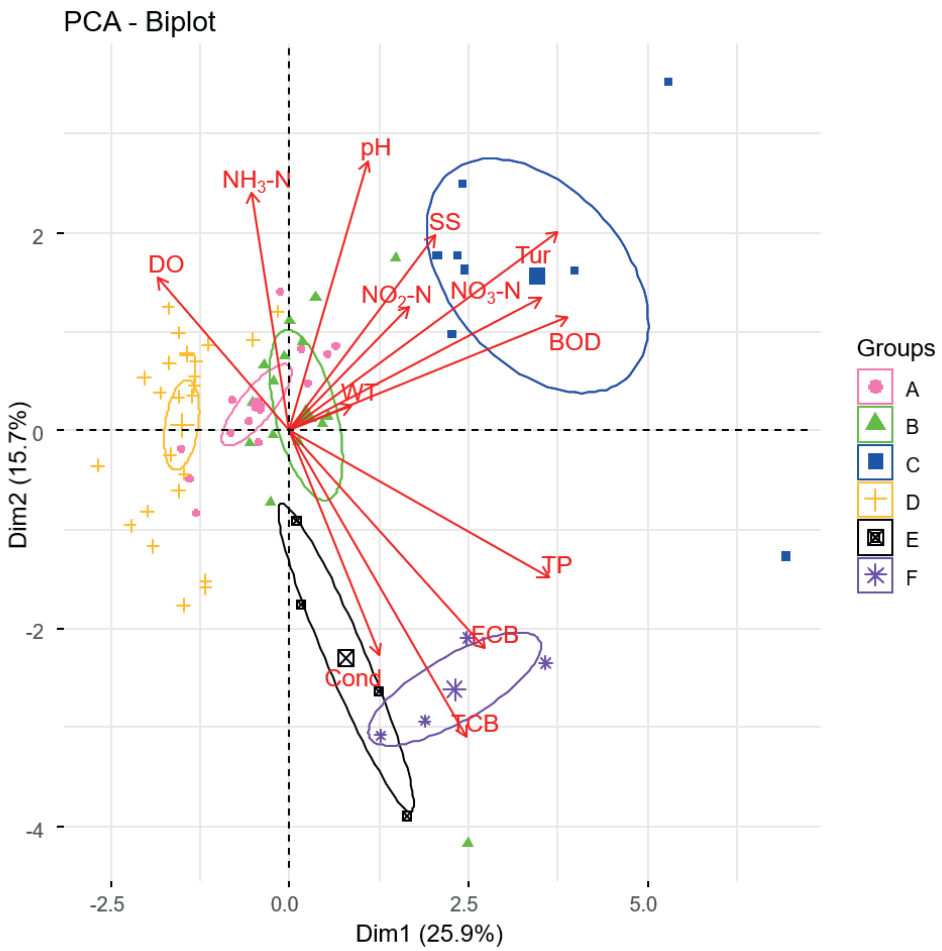

Figure 6. PCA of 13 water quality parameters for 6 clusters.

3.3 Appropriate management of the wetland

3.3.1 Controlling water levels in wetland

The inflowing water entered the reservoir as a plunging underflow creating increased Tur, WT and DO of the bottom water (Huang *et al*., 2014) but the self-purification process could take place on the water flow (Zubaidah *et al*., 2019). Therefore, the management that leads to good water quality (Cluster D) in Bungboraped wetland, should be the current consumption to maintain the minimum water level (+23 m, MSL) in the dry period (Sriwongsitanon et al., 2007) and encourage water to overflow (+24 m, MSL) the dike during the wet period.

3.3.2 Sediment management

The main cause of water turbidity is human activity such as dredging and pumping machines, and aquatic plant that are affected on nitrogen biogeochemical cycles and wetland sediments. The setup sediment traps in the drain system from agriculture area and aquatic plant control are decrease sediment (Urakawa and Bernhard, 2017; Han *et al*., 2019; Kiesel *et al*., 2009).

4. Conclusion and Recommendation

The characteristics of water quality in the Bungboraped wetland can be divided into 6 clusters which were affected by the activity in each space and time. BOD in all 5 clusters were over Thai standard and other parameters shown different characteristics, depending on the location and pattern of dredging and pumping sediment, quantity of water and water quality of runoff. Cluster D had good water quality, because there was enough water to let the water body in better condition. The result of SOM leads to the distribution of clusters which are in the direction of the water quality pattern in PCA.

Therefore, the results of the study provided good information, hopefully leading to activities that help improving the water quality in Bungboraped wetland. By keeping the good water quality, inducing the water flow over the dike in the wet period, and also avoiding activities that affect the water flow and sediment management at the source. Cluster D was the best example to follow in managing the water quality in Bungboraped wetland and the results can be applied to all wetlands with have water flow during in the wet period.

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